Measurements of the braching fractions for $\psi(3770) \to D^0\bar{D}^0,\ D^+D^-,\ D\bar{D}$ and the resonance parameters of $\psi(3770)$ and $\psi(2S)$

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We report measurements of the branching fractions for $\psi(3770) \to D^0\bar{D}^0, D^+D^-,\ D\bar{D}$ and resonance parameters of $\psi(3770)$ and $\psi(2S)$. By analyzing the line-shapes of the cross sections for inclusive hadron, $D^0\bar{D}^0$ and D^+D^- event production in the range from 3.660 GeV to 3.872 GeV covering both $\psi(2S)$ and $\psi(3770)$ resonances, we extract the branching fractions for $\psi(3770)$ decay into $D^0\bar{D}^0$ and D^+D^- respectively to be $B(\psi(3770) \to D^0\bar{D}^0) = (46.7 \pm 4.7 \pm 2.3)\%$ and $B(\psi(3770) \to D^+D^-) = (36.9 \pm 3.7 \pm 2.8)\%$, which give $B(\psi(3770) \to D\bar{D}) = (83.6 \pm 7.3 \pm 4.2)\%$ and non-$D\bar{D}$ branching fraction of $\psi(3770)$ to be $B(\psi(3770) \to non-D\bar{D}) = (16.4 \pm 7.3 \pm 4.2)\%$. We meanwhile obtain the resonance parameters of $\psi(3770)$ and $\psi(2S)$ to be $M_{\psi(3770)} = 3772.2 \pm 0.7 \pm 0.3$ MeV, $\Gamma^{\rm tot}_{\psi(3770)} = 26.9 \pm 2.4 \pm 0.3$ MeV and $\Gamma^{ee}_{\psi(3770)} = 251 \pm 26 \pm 11$ eV; $M_{\psi(2S)} = 3685.5 \pm 0.0 \pm 0.3$ MeV, $\Gamma^{\rm tot}_{\psi(2S)} = 331 \pm 58 \pm 2$ keV and $\Gamma^{ee}_{\psi(2S)} = 2.330 \pm 0.036 \pm 0.110$ keV; as well as the R value for the light hadron production directly through one photon annihilation to be $R_{uds} = 2.262 \pm 0.054 \pm 0.109$ in this energy region.

PACS numbers:

The $\psi(3770)$ resonance was discovered by MARK-I Collaboration in analysis of e^+e^- annihilation into hadrons 29 years ago [1]. Since its mass is above open charm-pair threshold and its width is two orders of magnitude larger than that of the $\psi(2S)$, it is thought to decay almost entirely to pure $D\bar{D}$ [2]. However, there were historically large discrepancies between the observed cross sections for $D\bar{D}$ and $\psi(3770)$ production in the e^+e^- annihilation. The observed cross section $\sigma^{\rm obs}_{\psi(3770)}$ for $\psi(3770)$ production can be obtained based on $\psi(3770)$ resonance parameters [3] and radiative corrections [4], which yield $\sigma^{\rm obs}_{\psi(3770)} = 8.12 \pm 1.56$ nb at the center-of-mass (c.m.) energy $E_{\rm cm} = 3.7699$ GeV and $\sigma^{\rm obs}_{\psi(3770)} = 7.53 \pm 1.44$ nb at $E_{\rm cm} = 3.773$ GeV. There are three absolute measurements [5][6][7] of the observed cross sections for $D\bar{D}$ production in the e^+e^- annihilation nearby the peak of $\psi(3770)$, which are summarized in table I. With the observed cross section $\sigma^{\rm obs}_{D\bar{D}} = 5.0 \pm 0.6$ nb for $D\bar{D}$ production at $E_{\rm cm} = 3.768$ GeV measured by MARK-III Collaboration, one historically found that about 38% [8] of $\psi(3770)$ does not decay into $D\bar{D}$ final states. Scaling the $\sigma^{\rm obs}_{D\bar{D}}$ measured at $E_{\rm cm} = 3.768$ GeV by using PDG $\psi(3770)$ parameters [3] yields the expected-observed cross section to be $\sigma^{\rm scaled}_{D\bar{D}} = 4.7 \pm 0.6$ nb at $E_{\rm cm} = 3.773$ GeV. The weighted average of the three cross sections listed in the second row of table I is $\bar{\sigma}^{\rm obs}_{D\bar{D}} = 6.25 \pm 0.15$ nb. Comparing the two observed cross sections for $\psi(3770)$ and $D\bar{D}$ production one finds that $(17.0 \pm 16.0)\%$ of $\psi(3770)$ does not decay into $D\bar{D}$, where the large error is dominated by the uncertainties in the resonance parameters of $\psi(3770)$.

To understand the discrepancy between the $\sigma^{\rm obs}_{\psi(3770)}$ and $\sigma^{\rm obs}_{D\bar{D}}$, one has to more precisely measure both the $\psi(3770)$ resonance parameters and the $D\bar{D}$ cross section, search for some non-$D\bar{D}$ decays of $\psi(3770)$ and directly measure the branching fraction for $\psi(3770) \to D\bar{D}$. To reduce some possible systematic shifts in comparison of the two cross sections from different experiments due to normalizations, one had better perform to simultaneously measure the $\psi(3770)$ resonance parameters and the $D\bar{D}$ cross section with a same data set. A better way to measure the inclusive branching fraction for $\psi(3770) \to D\bar{D}$ is simultaneously to analyze the energy dependent cross sections for the inclusive hadron, $D^0\bar{D}^0$ and D^+D^- event production in the energy range covering both $\psi(2S)$ and $\psi(3770)$ resonances. In this way one can also more accurately measure the resonance parameters of both the $\psi(3770)$ and $\psi(2S)$, since they are correlated each other in analysis of the cross section scan data.

In this Letter, we present a line-shape analysis of the inclusive hadron, $D^0\bar{D}^0$ and D^+D^- event production, by which we extract the branching fractions for $\psi(3770) \to$

TABLE I: The observed $D\bar{D}$ cross sections $\sigma^{\rm obs}_{D\bar{D}}$ which were directly measured by MARK-III, CLEO and BES Collaborations, where $^{\rm scaled}$ means that the observed cross section is scaled from the measured value at 3.768 GeV to that at 3.773 GeV based on PDG $\psi(3770)$ resonance parameters.

$E_{\rm cm}$ (GeV)	MARK-III (nb)	CLEO (nb)	BES (nb)
3.768	5.0 ± 0.6		
3.773	$4.7 \pm 0.6^{\rm scaled}$	6.39 ± 0.16	5.93 ± 0.58

for the first time, and meanwhile measure the resonance parameters of $\psi(3770)$ and $\psi(2S)$ with improved precision on $\psi(3770)$ resonance parameters and with precision in measuring leptonic width of $\psi(2S)$ comparable to the current PDG world averages. From this analysis we also measure the R value for light hadron production directly through one photon annihilation in the energy region from 3.660 GeV to 3.872 GeV. The analysis is based on the data taken with the BES-II detector [9] at the BEPC Collider during the time period from March to April, 2003.

The observed hadronic cross section is determined by the relation

$$\sigma^{\rm obs}_{\rm had} = \frac{N^{\rm obs}_{\rm had}}{L\ \epsilon_{\rm had}\ \epsilon^{\rm trig}_{\rm had}}, \tag{1}$$

where $N^{\rm obs}_{\rm had}$ is the number of the observed hadronic events, L is the integrated luminosity, $\epsilon_{\rm had}$ is the efficiency for detection of the inclusive hadronic events and $\epsilon^{\rm trig}_{\rm had}$ is the trigger efficiency for collecting the hadronic events in on-line data acquisition.

The hadronic events are required to have more than 2 good charged tracks, each of which is required to satisfy the following selection criteria: (1) the charged track must be with a good helix fit and the number of dE/dx hits per charged track is required to be greater than 14; (2) the point of the closest approach to the beam line must have radius ≤ 2 cm; (3) $|\cos\theta| < 0.84$, where θ is the polar angle of the charged track; (4) $2.0\ ns\ < T_{TOF} < T_p + 2.0\ ns$, where T_{TOF} is the time-of-flight of the charged particle, and T_p is the expected time-of-flight of proton with a given momentum; (5) the charged track must not be identified as a muon; (6) $p < E_b + 0.1 \times E_b \times \sqrt{(1+E_b^2)}$, where p is the charged track momentum and E_b is the beam energy in GeV; (7) for the charged track, the energy deposited in the BSC should be less than 1.0 GeV. In addition, the total energy deposited by an event in the BSC should be greater than 28% of the beam energy. Furthermore, the selected tracks must not all point into the same hemisphere in the z direction.

Some beam-gas associated background events can also

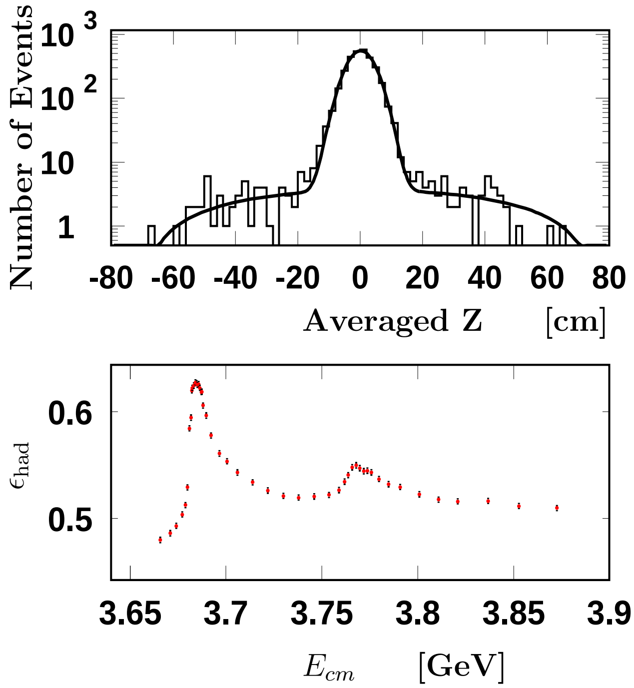

FIG. 1: (a) the distribution of the averaged z of the events satisfying the hadronic event selection criteria, where the histogram shows the events from the data, and the curves give the best fit to the z distribution; (b) the efficiencies for detection of the inclusive hadronic events vs the nominal center-of-mass energies.

ground events are produced at random z positions in the beam pipe, while the hadronic events are produced around $z = 0$, this characteristic can be used to distinguish the hadronic events from the beam-gas associated background events. Fig. 1(a) shows the distribution of the averaged z of the accepted events which satisfy the selection criteria. Using a Gaussian function plus a second order polynomial to fit the averaged z distribution of the events, we obtain the number, $N^{\rm zfit}_{\rm had}$, of the candidates for hadronic events. This number of candidates for hadronic events contains some contaminations from some background events such as $e^+e^- \to \tau^+\tau^-$, $e^+e^- \to (\gamma)e^+e^-$, $e^+e^- \to (\gamma)\mu^+\mu^-$, and two-photon processes. The number of the background events, $N_{\rm b}$, due to these processes can be estimated by means of Monte Carlo simulation. Subtracting $N_{\rm b}$ from $N^{\rm zfit}_{\rm had}$ yields the number of the observed hadronic events, $N^{\rm obs}_{\rm had}$. The systematic uncertainty in measuring the produced hadronic events due to the hadronic event selection criteria is estimated to be about $\sim 2.5\%$.

The integrated luminosities of the data sets are determined using large-angle Bhabha scattering events, which satisfy the following selection criteria: (1) two charged tracks with total charge zero, for each track, the point radius < 1.5 cm and $|z| < 15$ cm where $|z|$ is measured along the beam line from the nominal beam crossing point; (2) each track is required to satisfy $|\cos\theta| < 0.7$, where θ is the polar angle of the charged track, (3) it is required that the energy deposited for each charged track in the BSC be greater than 1.1 GeV and at least the magnitude of one charged track momentum be greater than $0.9E_{\rm b}$, (4) no track goes through the rib regions of the BSC. The systematic uncertainty in the measured luminosities arises mainly from the difference between the data and Monte Carlo simulation. The total uncertainty is estimated to be $\sim 1.8\%$.

The detection efficiency for hadronic events is determined via a special Monte Carlo generator [10] in which the radiative corrections to α^2 order are taken into account. These generated events are simulated with the GEANT3-based Monte Carlo simulation package [11]. The systematic uncertainty in the efficiencies due to the generator is estimated to be $\sim$ 2.0% ($\sim$ 0.7%) for reconstruction of the hadronic events from $\psi(3770)$ and $\psi(2S)$ decays (from continuum hadrons). Fig. 1(b) shows the Monte Carlo efficiencies for detection of the hadronic events produced at the different nominal center-of-mass energies. These efficiencies are used in the measurements of the observed inclusive hadronic cross sections at each of the energy points.

The trigger efficiencies are obtained by comparing the responses to different trigger requirements in the data taken at 3.097 GeV during the cross section scan experiment. The efficiencies are measured to be $\epsilon_{\rm trig} = (100.0^{+0.0}_{-0.5})\%$ for both the $e^+e^- \to (\gamma)e^+e^-$ and $e^+e^- \to$ *hadrons* events.

The observed cross section for $D^0\bar{D}^0$ (or D^+D^-) production is determined based on the number $N_{D^0_{\rm tag}}$ (or $N_{D^+_{\rm tag}}$) of the reconstructed D^0 (or D^+) events by

$$\sigma^{\rm obs}_{D^0\bar{D}^0 ({\rm or}\ D^+D^-)} = \frac{N_{D^0_{\rm tag}} ({\rm or}\ N_{D^+_{\rm tag}})}{2 \times L \times B \times \epsilon}, \qquad (2)$$

where L is the integrated luminosity of the data set used in the analysis, B is the branching fraction for the decay mode in question, and ϵ is the efficiency determined from Monte Carlo simulation for reconstruction of this decay mode. The observed numbers, $N_{D^0_{\rm tag}}$ (or $N_{D^+_{\rm tag}}$), of the singly tagged D^0 (or D^+) are obtained by analyzing the invariant mass spectra of $K^\mp\pi^\pm$ and $K^\mp\pi^\pm\pi^\pm\pi^\mp$ (or $K^\mp\pi^\pm\pi^\pm$) as discussed in detail in Ref. [12]. As an example, Fig. 2 shows the distributions of the invariant masses of $K^-\pi^+$ combinations observed from 14 data sets collected at different energy points in $\psi(3770)$ resonance region.

Using the methods discussed above and in Ref. [12], we obtain the observed cross sections for both the inclusive hadron and $D\bar{D}$ event production at the energies at

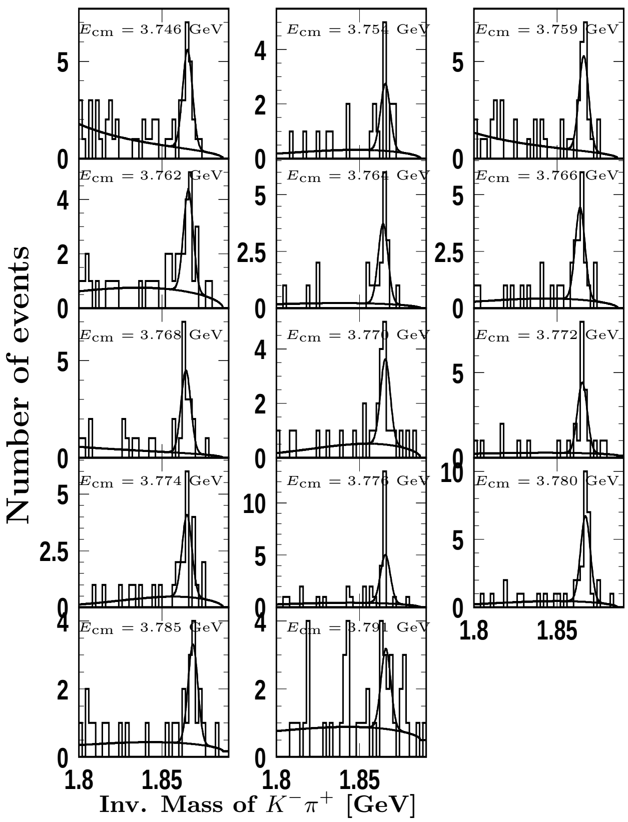

FIG. 2: The distributions of the invariant masses of the $K^-\pi^+$ combinations from the data sets taken at different nominal c.m. energy.

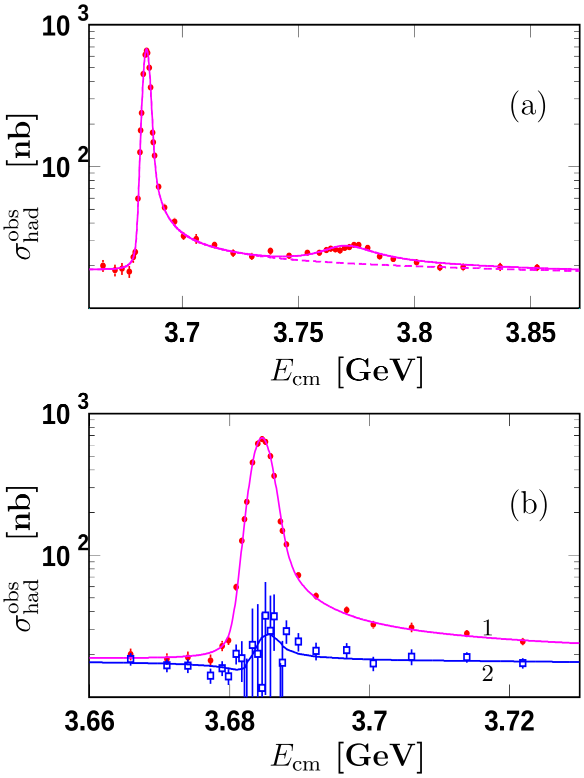

FIG. 3: The hadronic cross sections versus the nominal center-of-mass energies, where (a) the points with error show the observed cross sections, the solid line shows the fit to the cross sections and the dashed line represents the contributions from J/ψ, $\psi(2S)$ and continuum hadron production; where (b) the points with error show the observed cross sections and the line 1 gives the fit to the data in $\psi(2S)$ resonance region, while the squares with error show the observed cross sections for the continuum hadron production, which are corrected for the radiative corrections; the line 2 gives the fit to the cross sections (see text).

cross sections (points with error) for inclusive hadronic event production, while Fig. 4(b) and 4(c) respectively display the observed cross sections (points with error) for $D^0\bar{D}^0$ and D^+D^- production, where the error bars represent the combined statistical and point-to-point systematic uncertainties including the statistical uncertainties in the luminosity and the efficiencies for detection of the hadronic events and Bhabha events.

The determination of the branching fractions for $\psi(3770) \to D^0\bar{D}^0$, D^+D^-, and $D\bar{D}$ is accomplished by simultaneously fitting the observed cross sections for $\psi(2S)$, $\psi(3770)$, $D^0\bar{D}^0$ and D^+D^- to functions that describe the combined $\psi(2S)$, $\psi(3770)$ resonance shapes, the tail of J/ψ resonance and the non-resonant hadronic background, as well as the partial $\psi(3770)$ resonance shapes for $\psi(3770) \to D^0\bar{D}^0$ and $\psi(3770) \to D^+D^-$. The functions are corrected for the radiative corrections [4][13].

Breit-Wigner function

$$\sigma^{\rm B}(s^{'}) = \frac{12\pi\Gamma^{ee}\Gamma^{h}}{(s^{'}-M^2)^2+(\Gamma^{\rm tot}M)^2}, \qquad (3)$$

to describe their production, where $s^{'}$ is the squared actual energy which produces the hadronic events, M and $\Gamma^{\rm tot}$ are respectively the masses and total widths of the resonances, and Γ^{ee} and Γ^{h} are the partial widths to e^+e^- channel and to the inclusive hadronic final states, respectively. Assuming that there are no other new structures and effects except the $\psi(3770)$ resonance and the continuum hadron production in the energy region from 3.70 GeV to 3.86 GeV, we use the pure p-wave Born order Breit-Wigner function with an energy-dependent total width to describe the $\psi(3770)$ production and the

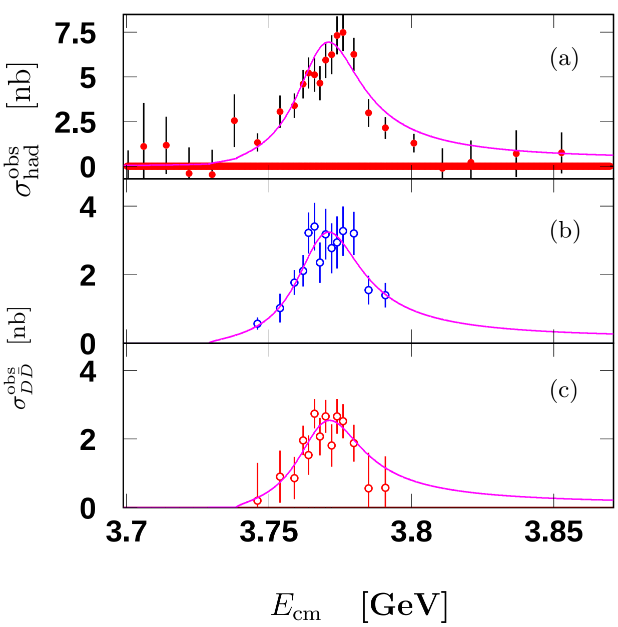

FIG. 4: The observed cross sections versus the nominal center-of-mass energies, where (a) shows the inclusive hadronic event production, (b) and (c) show the $D^0\bar{D}^0$ and D^+D^- event production, respectively; the points with error are the data, while the lines are the fits to the data.

decays. The $\psi(3770)$ resonance shape is taken as

$$\sigma^{\rm B}_{\psi(3770)}(s') = \frac{12\pi\Gamma^{ee}_{\psi(3770)}\Gamma^{\rm tot}_{\psi(3770)}(s')}{(s'-M^2_{\psi(3770)})^2+[M_{\psi(3770)}\Gamma^{\rm tot}_{\psi(3770)}(s')]^2}, \tag{4}$$

while the $D^0\bar{D}^0$, D^+D^- (or $D\bar{D}$) resonances shapes are taken as

$$\sigma^{\rm B}_{D\bar{D}}(s') = \frac{12\pi\Gamma^{ee}_{\psi(3770)}\Gamma_{D\bar{D}}(s')}{(s'-M^2_{\psi(3770)})^2+[M_{\psi(3770)}\Gamma^{\rm tot}_{\psi(3770)}(s')]^2}, \tag{5}$$

where $M_{\psi(3770)}$ and $\Gamma^{ee}_{\psi(3770)}$ are the mass and leptonic width of the $\psi(3770)$ resonance, respectively; $\Gamma_{D\bar{D}}$ is the partial width of $\psi(3770)$ decay into $D\bar{D}$; $\Gamma^{\rm tot}_{\psi(3770)}(s')$ and $\Gamma_{D\bar{D}}(s')$ are chosen to be energy dependent, which are defined as

$$\Gamma^{\rm tot}_{\psi(3770)}(s') = \Gamma_{D^0\bar{D}^0}(s') + \Gamma_{D^+D^-}(s') + \Gamma_{{\rm non}-D\bar{D}}(s'), \tag{6}$$

where

$$\Gamma_{D^0\bar{D}^0}(s') \;=\; \Gamma_0\;\theta_{D^0\bar{D}^0}\frac{(p_{D^0})^3}{(p^0_{D^0})^3}\frac{1+(rp^0_{D^0})^2}{1+(rp_{D^0})^2}B_{00}, \tag{7}$$

$$\Gamma_{D^+D^-}(s') \;=\; \Gamma_0\;\theta_{D^+D^-}\frac{(p_{D^+})^3}{(p^0_{D^+})^3}\frac{1+(rp^0_{D^+})^2}{1+(rp_{D^+})^2}B_{+-}, \tag{8}$$

and

$$\Gamma_{{\rm non}-D\bar{D}}(s') = \Gamma_0\;[1-B_{00}-B_{+-}], \tag{9}$$

where p^0_D and p_D are respectively the momenta of the D mesons produced at the peak of $\psi(3770)$ and at the actual c.m. energy $\sqrt{s'}$; Γ_0 is the total width of the $\psi(3770)$ at its peak, $B_{00} = B(\psi(3770) \to D^0\bar{D}^0)$ and $B_{+-} = B(\psi(3770) \to D^+D^-)$ are the branching fractions for $\psi(3770) \to D^0\bar{D}^0$ and $\psi(3770) \to D^+D^-$, respectively, which are the fitted parameters, and r is the interaction radius of the $c\bar{c}$, which is left free in the fit; $\theta_{D^0\bar{D}^0}$ and $\theta_{D^+D^-}$ are the step functions to account for the thresholds of the $D^0\bar{D}^0$ and D^+D^- production, respectively.

The non-resonant hadronic background shape is taken as

$$\sigma^{nrsnt}_h = \int_0^\infty ds'' G(s,s'')\int_0^1 dx\frac{R_{uds}(s')\sigma^B_{\mu^+\mu^-}(s')}{|1-\Pi(s')|^2}F(x,s)$$
$$+f_{D\bar{D}}\left[(\frac{p_{D^0}}{E_{D^0}})^3\theta_{D^0\bar{D}^0}+(\frac{p_{D^+}}{E_{D^+}})^3\theta_{D^+D^-}\right]\sigma^B_{\mu^+\mu^-}(s'), \tag{10}$$

with $s' = s(1-x)$, where x is a parameter related to the total energy of the emitted photons and $\sqrt{s}$ is the nominal c.m. energy, $F(x,s)$ is the sampling function [4], $1/|1-\Pi(s(1-x))|^2$ is the vacuum polarization correction function [13] including the contributions from all 1^{--} resonances, the QED continuum hadron spectrum as well as the contributions from the lepton pairs (e^+e^-, $\mu^+\mu^-$ and $\tau^+\tau^-$) [10]; $\sigma^B_{\mu^+\mu^-}(s')$ is the Born cross section for $e^+e^- \to \mu^+\mu^-$, E_{D^0} and E_{D^+} are respectively the energies of D^0 and D^+ mesons produced at the actual energy $\sqrt{s'}$, $f_{D\bar{D}}$ is a parameter to be fitted, and $R_{uds}(s')$ is the R value for the light hadron production through one photon annihilation directly. In the fit we take the $R_{uds}(s')$ as a constant in the energy region and left it free; we fix the J/ψ resonance parameters at the values given by PDG [3]. We also consider the effects of the BEPC energy spread on the observed cross sections in the fit. $G(s,s'')$ in Eq. (10) is the Gaussan function to describe the c.m. energy distribution of the BEPC machine.

The curves in Fig. 3 and Fig. 4 show the fits to the data. Fig. 3(a) shows the observed cross sections with the fit to the data, where the points with error show the observed cross sections and the error is combined from statistical and point-to-point systematic uncertainties arising from the statistical uncertainties in the efficiencies for detection of the hadronic events and Bhabha events; the solid line shows the fit to the cross sections and the dashed line represents the contributions from J/ψ, $\psi(2S)$ and continuum hadron production. To examine the contribution from the vacuum polarization corrections to the Born hadronic cross section due to one photon annihila-

$\psi(3770)$ as well as J/ψ from the observed cross sections to yield the expected cross sections of the continuum hadron production corrected with the radiative effects, which is given by Eq. (10). The squares with error in Fig. 3(b) show the yielded-expected cross sections, where the errors are the originally absolute errors of the totally observed cross sections as shown in Fig. 3(a). The line 2 in Fig. 3(b) shows the fit to the expected cross sections of the continuum hadron production corrected for the radiative effects. Fig. 4(a) shows the observed cross sections for the inclusive hadronic event production, where the contributions from J/ψ and $\psi(2S)$ radiative tails as well as the continuum hadron production are removed. Fig. 4(b) and Fig. 4(c) display the observed cross sections for $D^0\bar{D}^0$ and D^+D^- production, respectively, where the points with error show the observed cross sections, while the lines give the fits to the data. The error is combined from the statistical and point-to-point systematic arising from the statistical uncertainties in the efficiencies for detection of the singly tagged D events and Bhabha events. The fit gives $\chi^2/\text{n.o.f} = 65.4/64 = 1.02$. In the data reduction, the number of the singly tagged D^0 (or D^+) events are removed from the inclusive hadronic event samples before calculating the hadronic cross section and its error based on Eq.(1). These make the hadronic event samples and the singly tagged D samples be independent.

The results from this fit are

$$B(\psi(3770) \to D^0\bar{D}^0) = (46.7 \pm 4.7 \pm 2.3)\%$$

and

$$B(\psi(3770) \to D^+D^-) = (36.9 \pm 3.7 \pm 2.8)\%,$$

where the first error is statistical and second systematic arising from uncanceled systematic uncertainties in the measured σ_{had} ($\sim 2.8\%$) in $\sigma_{D^0\bar{D}^0}$ ($\sim 4.1\%$), and in $\sigma_{D^+D^-}$ ($\sim 7.0\%$). Considering the correlation between the two branching fractions obtained from the fit, we obtain the branching fraction for $\psi(3770) \to D\bar{D}$ to be

$$B(\psi(3770) \to D\bar{D}) = (83.6 \pm 7.3 \pm 4.2)\%,$$

which results in the non-$D\bar{D}$ branching fraction to be

$$B(\psi(3770) \to non - D\bar{D}) = (16.4 \pm 7.3 \pm 4.2)\%.$$

The fit gives the BEPC machine energy spread $\sigma_{\text{E}_{\text{BEPC}}} = (1.343 \pm 0.029)$ MeV. From the fit we obtain the R value for the light hadron production due to one photon annihilation in the energy region between 3.660 GeV and 3.872 GeV to be

$$R_{uds} = 2.262 \pm 0.054 \pm 0.109,$$

where the first error is statistical and the second systematic arising from the uncertainty in the measured cross

($\sim 0.2\%$). The fit also gives the resonance parameters of $\psi(3770)$ and $\psi(2S)$ to be $M_{\psi(3770)} = 3772.2 \pm 0.7 \pm 0.3$ MeV, $\Gamma^{\text{tot}}_{\psi(3770)} = \Gamma_0 = 26.9 \pm 2.4 \pm 0.3$ MeV, $\Gamma^{ee}_{\psi(3770)} = 251 \pm 26 \pm 11$ eV; $M_{\psi(2S)} = 3685.5 \pm 0.0 \pm 0.3$ MeV, $\Gamma^{\text{tot}}_{\psi(2S)} = 331 \pm 58 \pm 2$ keV, $\Gamma^{ee}_{\psi(2S)} = 2.330 \pm 0.036 \pm 0.110$ keV, where the first error is statistical and the second systematic arising from the uncertainties in the measured σ_{had} ($\sim 4.4\%$), in $\sigma_{D^0\bar{D}^0}$ ($\sim 4.5\%$), and in $\sigma_{D^+D^-}$ ($\sim 7.4\%$). The measured mass difference between $\psi(3770)$ and $\psi(2S)$ is $\Delta M = 86.6 \pm 0.7$ MeV. The measured values of the $\psi(3770)$ resonance parameters yield the cross section for $\psi(3770)$ production at its peak to be $\sigma^{\text{prd}}_{\psi(3770)} = (9.63 \pm 0.66 \pm 0.35)$ nb, corresponding the observed cross section $\sigma^{\text{obs}}_{\psi(3770)} = (6.94 \pm 0.48 \pm 0.28)$ nb, which is consistent within error with $\sigma^{\text{obs}}_{\psi(3770)} = (8.12 \pm 1.56)$ nb at $\psi(3770)$ peak obtained based on the PDG $\psi(3770)$ resonance parameters.

The measured branching fractions yield the ratio of the partial widths $\Gamma_{D^0\bar{D}^0}/\Gamma_{D^+D^-} = 1.27 \pm 0.12 \pm 0.08$, which agrees with the prediction of 1.36 by Eichten et al. [14] and is in good agreement with $1.41 \pm 0.23 \pm 0.11$ measured by BES [15]. The measured widths of the resonances yield the leptonic branching fractions to be $BF(\psi(3770) \to e^+e^-) = (0.93 \pm 0.06 \pm 0.03) \times 10^{-5}$ and $BF(\psi(2S) \to e^+e^-) = (0.704 \pm 0.122 \pm 0.033)\%$.

We find that the continuum background shape affect the measured total and leptonic widths of the resonances from the line-shape analysis. If we take the non-resonant hadronic background shape as

$$\begin{aligned}\sigma_h^{nrsnt} = \; & h\, \sigma^B_{\mu^+\mu^-}(s') \\ & + f_{D\bar{D}} \left[\left(\frac{p_{D^0}}{E_{D^0}}\right)^3 \theta_{D^0\bar{D}^0} + \left(\frac{p_{D^+}}{E_{D^+}}\right)^3 \theta_{D^+D^-} \right] \sigma^B_{\mu^+\mu^-}(s'),\end{aligned} \tag{11}$$

in fitting the data (where h is a parameter in the fit), we would obtain $\Gamma^{\text{tot}}_{\psi(2S)} = 290 \pm 59 \pm 5$ keV, $\Gamma^{ee}_{\psi(2S)} = 2.378 \pm 0.036 \pm 0.103$ keV, $\Gamma^{\text{tot}}_{\psi(3770)} = 27.3 \pm 2.5 \pm 1.1$ MeV and $\Gamma^{ee}_{\psi(3770)} = 256 \pm 27 \pm 13$ eV, and almost unchanged the measured masses of the resonances. This fit yields $\chi^2/\text{n.o.f} = 75.3/64 = 1.18$. These indicate that the vacuum polarization corrections to the Born order cross sections for the continuum hadron production can not be ignored in precisely measuring the resonance parameters of the narrow resonances like J/ψ and $\psi(2S)$ as well as $\Upsilon(1S)$ etc. in e^+e^- cross section scan experiments. Ignoring the effects of the vacuum polarization corrections on the continuum hadron production cross sections in analysis of the cross section scan data taken in the $\psi(2S)$ resonance region would decrease the $\psi(2S)$ total width by about 40 keV.

In summary, we measured the branching fractions for $\psi(3770) \to D^0\bar{D}^0, D^+D^-$ and $\psi(3770) \to \text{non} - D\bar{D}$ for the first time and measured the resonance parameters of $\psi(3770)$ and $\psi(2S)$ with improved precision on $\psi(3770)$ resonance parameter and with a comparable precision to

same data samples, we also measured the R value for the continuum light hadron production with a precision of about $\pm 5\%$. From this analysis we directly observed the effects of the vacuum polarization on the observed cross sections of the continuum hadron production in the neighborhood of the $\psi(2S)$ resonance.

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